Tailoring Enterprise Systems Engineering Policy for Project Scale and Complexity

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INTRODUCTION

Space systems are characterized by varying degrees of scale and complexity. Accordingly, cost-effective implementation of systems engineering also varies depending on scale and complexity. Recognizing that systems engineering and integration happen everywhere and at all levels of a given system and that the life cycle is an integrated process necessary to mature a design, the National Aeronautic and Space Administration's (NASA's) Marshall Space Flight Center (MSFC) has developed a suite of customized implementation approaches based on project scale and complexity. While it may be argued that a top-level system engineering process is common to and indeed desirable across an enterprise for all space systems, implementation of that top-level process and the associated products developed as a result differ from system to system. The implementation approaches used for developing a scientific instrument necessarily differ from those used for a space station.

At NASA, policy is captured in NASA Procedural Requirements (NPRs) and is used to communicate requirements and expectations to be implemented across the Agency. The scope of NPRs varies, covering legal policies and policies regarding property, procurement, financial management, etc. Program formulation and program management policies are captured in the 7000 and 8000 series of NPRs, respectively. NPRs describe expectations originating from NASA's customers and stakeholders, the Office of Management and Budget (OMB), Congress, Office of Federal Procurement Policy, etc. The requirements also capture expectations from lessons learned throughout the history of NASA and space flight. The NPRs communicate requirements for programs and projects and also the responsibility of Centers to develop and maintain an infrastructure that supports the development of NASA's strategic goals. It is through the NPRs and the Centers' responses that the Agency has been able to delegate authority to each of the 10 Centers in many areas, particularly programmatic and technical authority. It is through this delegation of authority that MSFC has taken the initiative to develop tailored recommendations for policy based on program and project scale and complexity.

INTEGRATION

For the purposes of this paper, the system being engineered is the establishment of policy expectations for all MSFC programs and projects. The elements of this policy include programmatic, technical, and safety and mission assurance.

The first objective was to integrate these elements into a single, 'one-stop shop,' so as to increase efficiencies in understanding that which is required. By doing so, it was also recognized that the Center would achieve better consistency in its systems engineering approach by reducing project-to-project variation in implementation for space systems of similar scale and complexity. Beginning with the expectations of stakeholders, MSFC flowed down the policy requirements and integrated them into Marshall Procedure Requirements (MPR) 7120.1, *MSFC Engineering and Program/Project Management Requirements* [1]. This document then served as the single starting point for all programs, projects, and activities as they began the challenge of planning the work required to properly execute each program or project. MPR 7120.1 points to more detailed requirements in peer-level supporting documentation for the 17 systems engineering processes and software engineering requirements. See Fig. 1.

Within MPR 7120.1, there are two primary programmatic governance options, one for space flight, NPR 7120.5, *Space Flight Program/Project Management* [2], and one for research and technology, NPR 7120.8, *Research and Technology Program/Project Management* [3]. The governance option dictates the programmatic rigor by which the work will be reviewed, as well as the life cycle expectations. Generally speaking, space flight programs and projects require more scrutiny because of the complexity of space flight and its inherent risk.

Integrating the Agency expectations into the 'one-stop shop,' MPR 7120.1, proved an excellent starting point, but the integration required was not yet complete. The derived expectations from the Center, including technical requirements stemming from MSFC's engineering heritage, needed to be integrated into the policy also. Having the complete flowdown of requirements integrated with the expectations of the Center provided a complete system of policy expectations for programs and projects. Requirements were to reflect 'what,' was to be accomplished whereas guidance and best practices were to reflect 'how' to implement the requirement. The purpose of keeping the tried-and-true implementation methods separate from the requirements was to enhance flexibility with designing implementation approaches, while still maintaining the knowledge gained from decades of designing, developing, testing, and flying space systems.

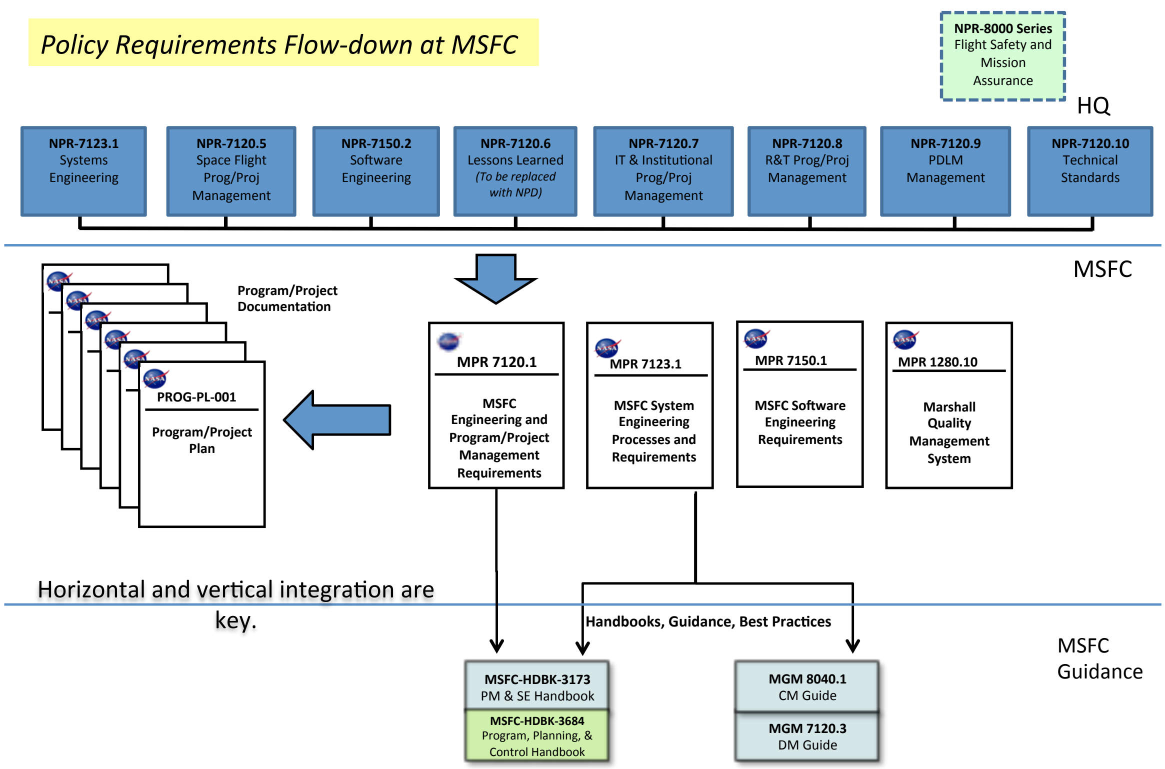

Fig. 1. MSFC Integrated Policy for Programs/Projects

PORTFOLIO

The next steps were to define the diversity of the portfolio of programs and projects at MSFC and to bring some order in which for policy to be tailored. MSFC is fortunate to have a vast portfolio. The Center has responsibilities ranging from launch vehicles, to spacecraft, to experiments, to testing piece parts for other stakeholders. The programs and projects also vary based on launch opportunities. The portfolio products fly on launch vehicles, balloons, sounding rockets, even an airplane. The diversity of work in which the Center is involved is extremely beneficial in terms of maintaining and enhancing the Center's engineering and program/project management capabilities. However, this diversity does represent some challenges with respect to policy and flexibility. To address the challenges resulting from a diverse portfolio, MSFC defined a set of mission types. The definitions include the Agency-defined mission categories, categories that are primarily based on costs, with Agency-defined payload risk classifications, i.e., classes A, B, C, or D. Table 1 shows the outcome of this definition effort: eight MSFC mission types. Note that the table was designed to capture the priority in which mission type decisions are made. For example, the primary factor in determining mission type is Program/Project Life Cycle Cost; therefore, that factor is listed first. Life cycle costs will most likely lead to the appropriate levels for national significance, risk tolerance, project complexity, etc., as the user works through the definition. It is worth noting that life cycle costs take into account the schedule afforded the project, time, and the size of the team. These key factors directly relate to project scale and complexity. Every distinction to be considered for determining the implementation approach and addressing policy completely and distinctly was integrated into the MSFC-defined mission types.

Table 1. MSFC Mission Types

Project and Activity Categorization/Mission Types								
	Projects						Activities	
	Type 1	Type 2		Type 3			Type 4	Type 5
		2.a	2.b	3.a	3.b	3.c		
Cost Guidance (Estimated LCC)	greater than $1B	$1B - $250M	$250M - $100M	$100M - $50M	$50M - $10M	less than $10M	typically [1] greater than $1M/yr or greater than $10M LCC	typically [1] less than $1M/yr or less than $10M LCC
Priority (Criticality to Agency Strategic Plan)	Any	Any	High	Medium or low priority	Low priority	Low to very low priority	High to Agency or Center	Medium or Low
Other Factors	Significant Radioative Material							
Decision Authority	NASA Associate Administrator	NASA Mission Directorate Associate Administrator		NASA Mission Directorate Associate Administrator or Designee			Center Director or Designee	Directorate/Office Manager or Designee
Governing PMC	Agency	Mission Directorate		Mission Directorate			CMC	Monthly Program Reviews Within Directorate/Office
National Significance	Very high	High	Medium	Medium	Low	Very Low		
Risk Tolerance	Class A Risk: Very low (minimized)	Class B Risk: Low	Class C Risk: Medium	Class D Risk: High	Class D Risk: High	Class D Risk: High		
Description of the Types of Mission	Human Space Flight or very large Science/Robotic Missions	Non-Human Space Flight or Science/Robotic Missions	Small Science (Human or Non human)	Smaller Science (Human or Non human)	Science (Human or non human)	Science (Human or non human)	Efforts supporting program/projects managed outside of MSFC, that come under the purview of the CMC per the criteria defined in MPR 7120.4	Efforts supporting program/project managed outside of MSFC, that do not come under the purview of the CMC per the criteria defined in MPR 7120.4
Complexity	Very high to high	High to Medium	Medium to Low	Low	Low	Low to Very Low		
Mission Lifetime (Primary Baseline Mission)	Long (>5 years)	Medium (2-5 years)	Short (<2 years)	Short (<2 years)	Short (<2 years)	Short (<2 years)		
Launch Constraints	Critical	Medium	Few to none	Few to none	Few to none	None		
Achievement of Mission Success Criteria	All practical measures are taken to achieve minimum risk to mission success. The highest assurance standards are used.	Stringent assurance standards with only minor compromises in application to maintain a low risk to mission success.	Medium or significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.	Significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.	Significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.	Significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.		
Examples	HST, Chandra, Cassini, JIMO, JWST, MPCV, SLS, ISS	MER, MRO, Discovery payloads, ISS Facility Class payloads, Attached ISS payloads	ESSP, Explorer payloads, MIDES, ISS complex sub rack payloads, PA-1, ARES 1-X, MEDLI, CLARREO, SAGE III, Calipso, ISERV	SPARTAN, GAS Can, technology demonstrators, simple ISS, express middeck and sub rack payloads, SMEX, MISSE-X, EV-2	IRVE-2, IRVE-3, HiFIRE, HyBoLT, ALHAT Earth Venture I, FASTSAT	DAWNAir, InFlame, Research, technology demonstrations, HEROES, SWORDS Payloads, Nanosails	ADDITIVE Manufacturing in Space	MSFC activities in support of a request from program/project outside of MSFC, for MSFC supporting activities. Subject to requesting organization's requirements.

LIFE CYCLES

There are seven life cycle types defined at NASA. (1) Uncoupled/loosely coupled programs are programs implemented under a broad theme, whose projects are independent of each other and do not have a common interface. The primary function of this life cycle is to oversee and manage the projects manifested under them. The Technology Demonstration Mission (TDM) is an example of an Uncoupled Program. (2) Another life cycle type is a Tightly Coupled Program. Tightly Coupled Programs are programs whose projects execute portions of the mission. Under Tightly Coupled Programs, no single project is capable of implementing a complete mission. The International Space Station (ISS) is an example of a Tightly Coupled Program. (3) Single Project Programs are programs that have combined program and project management approaches. These programs tend to have long development and/or operational lifetimes and represent a large investment of Agency resources. They develop elements and also integrate those elements into a system. The Space Launch System (SLS) is an example of a Single Program Project (SPP). (4) A project is a specific investment identified in a Program Plan. Projects have a management structure, defined requirements, life cycle cost, and possible interfaces to other projects, agencies, and international partners. The High Energy Replicated Optics to Explore the Sun (HEROS) project, flown on a balloon, is an example. (5) The Research & Technology (R&T) Program is an Agency program strictly comprised of R&T projects. The R&T Program life cycle is another program management function, similar to uncoupled and loosely coupled programs, whose focus is overseeing and managing the R&T projects underneath them. (6) Technology Development (TD) Projects utilize a life cycle for R&T projects whose Technology Readiness Level (TRL) is greater than five. For TRLs less than five, the (7) R&T Portfolio life cycle is used. An example of an R&T project is the Green Propellant Infusion Mission (GPIM).

Within each of the seven life cycles there are different programmatic requirements and different design review expectations. Technical requirement expectations are virtually the same, in that an assessment of the traditional 17 systems engineering processes is required of all life cycles. Safety and Mission Assurance requirement expectations will vary based on risk posture, flight carrier, and whether the program or project is manned or unmanned.

CUSTOMIZATION TOOL

In an effort to successfully conduct a variety of missions in a more timely and efficient manner, MSFC initiated an activity to review policy and develop a systematic method of providing a tailored starting point for programs and projects based on project scale and complexity. The activity also promoted better consistency by reducing the project-to-project variation of systems engineering implementation for space systems of similar scale and complexity. In essence, the challenge of marrying the integrated policy to the diverse portfolio of programs and projects to the life cycle was undertaken. Affordability, efficiency, and completeness led the MSFC team to develop a customization software application (tool) to answer the challenge. Given a project classification, customized implementation approaches of the MSFC systems engineering policy were developed on the basis of recognized best practices and lessons learned from similar systems. For each life cycle, the tool provides a comprehensive list of products and design reviews expected for each decision point, along with a recommendation for tailoring based on mission type.

Walking through the logic flow of the tool, as shown in Fig. 2, the user

1. Determines the type of governance to be used: space flight or research and technology
2. Determines the mission type: 1, 2a, 2b, 3a, 3b, 3c, 4, or 5, as defined in Table 1 above
3. Determines the program/project life cycle

Once all the selections have been made, the user is given a tailored set of minimum design reviews and their associated products for consideration, which is a subset of the complete integrated set of all expectations, i.e., worst case. Fig. 2 below captures all the options and gives the reader a complete picture of the integration within the tool. Note that for each of the reviews in the logic flow, the color of the text in the box is significant: black = Agency required review, green = MSFC added required review, blue = MSFC added optional review. Also note that although the option to select ‘Ground,’ ‘Manned,’ ‘Unmanned’ only appears on the right under R&T Governance, it is understood that space flight will be either ‘Manned’ or ‘Unmanned.’ The primary difference between ‘Manned’ and ‘Unmanned’ on either side of the logic flow will be in the Safety and Mission Assurance requirement set. The reason for showing these options under R&T is to make allowance for projects flown aboard airplanes. The result of the integrated customized implementation approaches supports the Center initiative of more informed risk-based decision-making and affordability. It is important to emphasize that the output of the tool represents a **recommended** starting point for addressing policy. The tool output

is not intended to be interpreted as a **required** starting point. The engineer is always expected to do what is appropriate for the circumstance.

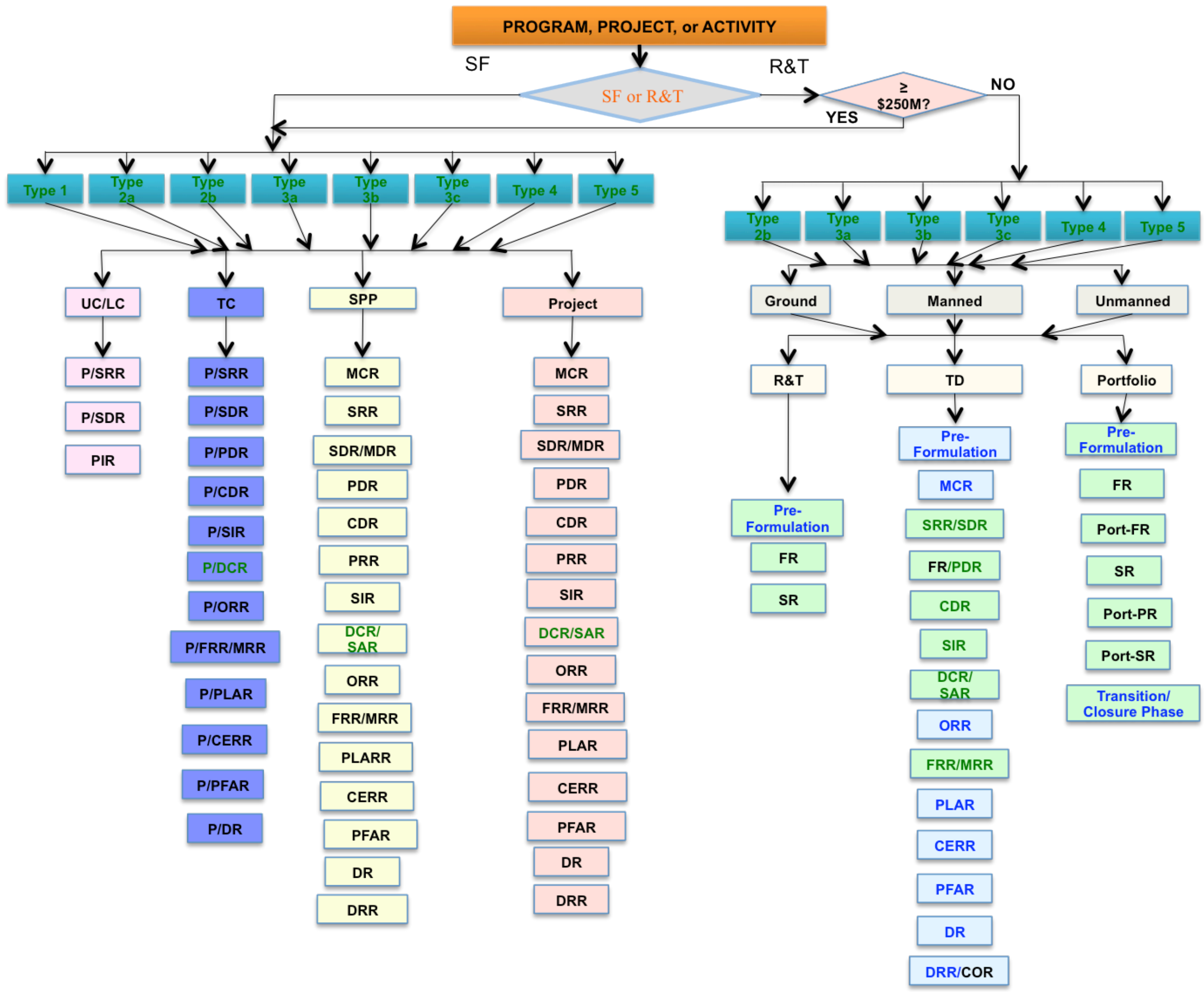

Fig. 2. Tailoring Logic Flow
(See page 7 for Acronym list)

COMPARE AND CONTRAST

Stepping through the tool, we will compare and contrast the SLS Program, an NPR 7120.5- governed Program, to the GPIM, an NPR 7120.8-governed mission. SLS has life cycle costs greater than $1 Billion, is of very high national significance, and has a very low-risk posture. It is a Type 1 on the MSFC Mission Types table. GPIM is between a $50 Million - $10 Million project of low national significance and has a high-risk posture. It is considered a Type 3b on the MSFC Mission Types table. As previously mentioned, SLS follows the SPP life cycle, while the GPIM, with a TRL level greater than five as of this date, follows the TD life cycle. The output of the tool shows the difference in the minimum set of design reviews required for each. See Table 2. The whole suite of reviews is expected of SLS, a very complex program, while a smaller number of reviews is expected for the GPIM, a low complexity project. Because SLS is an SPP, its reviews will address the program integration aspect of the project as well. Remember, SPPs are a combination of program and project functions. It could be considered a combination of the reviews shown under Tightly Coupled program and project. Because an SPP would combine these two perspectives into one review, the individual reviews are not listed separately below; however, addressing two perspectives does significantly change the scope of the review. Because the scope of the review is different, the product expectations will also be vastly different.

Table 2. Design Review Difference

SLS Reviews	GPIM Reviews
MCR	
SRR	SRR
SDR	
PDR	PDR
CDR	CDR
PRR	
SIR	SIR
DCR	DCR
ORR	
FRR	FRR
PLARR	
CERR	
PFAR	
DR	
DRR	

The product expectation differences are also captured in the tool and can be viewed as one delves deeper. By selecting the review of interest, the tool provides a listing of product expectations for that phase of the life cycle. SLS, because it is an SPP, would have the additional technical function of program integration, for which GPIM would not be responsible. The additional function would require the SLS product set to address the added scope. For example, SLS will produce Integrated Ascent Mission Timelines, where as the flight carrier for GPIM would produce this type product with inputs from GPIM.

From a programmatic perspective, both SLS and GPIM involve the same functions: Safety and Mission Assurance, risk management, basis of estimate, education outreach, lessons learned, etc. However, project complexity drives stand-alone products for each of these for SLS (28 stand -alone plans), while they can all be captured in the single project plan for GPIM.

Technically both projects would be required to do a Systems Engineering Management Plan, in which the traditional 17 systems engineering processes are assessed and that assessment captured. The magnitude of performing the work is different. As an example, both SLS and GPIM are required to do requirements management, but complexity differences between the two projects mean that the amount of work necessary to perform requirements management and flowdown for SLS differs greatly in magnitude from that required of GPIM.

SUMMARY

Taking a systems engineering and integration approach to the ***system*** of program and project management policy, MSFC has integrated myriad standards and expectations from the Agency with requirements of the Center and integrated those requirements with best practices and integrated mission types with NASA life cycles. This integration is performed one time for all the Center's programs and projects to use, allowing the program/project teams to apply their resources on developing an implementation approach that best matches their project scale and complexity. When thinking of it in terms of the Systems Engineering Vee [4], the Center, utilizing its heritage, has tackled the left hand side of the Vee, allowing the program and project teams to focus attention on the right hand side of the Vee, as they develop their implementation plans. Utilizing the tool allows a common basis for all MSFC programs and projects to make informed risk assessments, both at the engineering level and the management level. It also serves as a feedback mechanism for the implementers, based on lessons learned that could be applied to enhance the **system** for future generations. To date, the customization tool has been exercised on SLS, HEROES, 3D Print, the Lightning Imaging Sensor, and several other program and projects at MSFC. The consistency, repeatability, and efficiency resultant from this tool is expected to enhance MSFC's overall success. Through the use of the customization tool, the burden of finding the way through the maze of expectations has been lightened by quickly highlighting the appropriate, integrated, systems engineering policy path to consider, based on project scale and complexity. As a result, the project teams and their governing authorities are better equipped to tailor their implementation approaches in a more cost-effective manner.

ACRONYMS FOR FIG. 2

CDR-Critical Design Review
CERR-Critical Events Readiness Review
COR-Closeout Review
DCR-Design Certification Review
DR-Decommissioning Review
DRR-Disposal Readiness Review
FR-Formulation Review
FRR-Flight Readiness Review
MCR-Mission Concept Review
MDR-Mission Definition Review
MRR-Mission Readiness Review
ORR-Operational Readiness Review
P - Program
PDR-Preliminary Design Review
PFAR-Post-Flight Assessment Review
PIR-Program Implementation Review
PLAR-Post-Launch Assessment Review
PRR-Production Readiness Review
SAR-System Acceptance Review
SDR-System Definition Review
SIR-System Integration Review
SR-Status Review
SRR-Systems Requirements Review

REFERENCES

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[4] Benjamin S. Blanchard, *Systems Engineering Management,* 3rd edition, page 27.